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A PRECISION, THERMALLY-ACTIVATED DRIVER FOR SPACE APPLICATION

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This paper describes a space qualified, precision, large force, thermally-activated driver that has been developed jointly by the NASA Langley Research Center and PRC Kentron. The driver consists of a sealed hydraulic cylinder containing a metal bellows, a bellows plug, a coil spring, a spring retainer, an output shaft, a shaft guide, and a quantity of silicone oil. Temperature changes cause the silicone oil to expand or contract thus contracting or expanding the bellows/spring assembly thereby extending or retracting the output shaft.

INTRODUCTION

The primary objective of the first reflight of NASA's Long Duration Exposure Facility, the LDEF-1B mission planned for mid-1987, will be to establish the abundance of the rare actinide group elements in cosmic rays. These abundances, which hold clues to the origin and evolution of cosmic rays, will be determined through analysis of energetic particle tracks in stacks of thin plastic sheets after the sheets have been exposed in space for 2-1/2 years on the LDEF.

When energetic particles such as the actinide cosmic rays penetrate certain plastics, the molecular bonds in the plastic at the track site are damaged, and the degree of damage is proportional to the energy that was dissipated along the track. If the plastic sheets are etched after they are penetrated by elements, conical pits will result at each track site. The damaged plastic at the track site etches much faster than the undamaged plastic, and the increase in etch rate is a precise indicator of the degree of damage to the plastic molecular structure.

With proper information and control, scientists can determine the element responsible for a given track from the observed dimensions of the etch pits. By ratioing the number of tracks in the LDEF exposed plastics which result from elements of known abundance (the platinum-lead group) to the number of tracks which result from actinides, the abundance of the actinide elements will be established.

The main problem in implementing this experiment, however, results from the fact that the temperature of the plastic stacks at the time a track is produced is a critical item of information in the analysis of etch pits. It must be known to within 1°C. The precision, Thermally-Activated Driver

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(TAD) which is described in this paper was developed to be the heart of the Event Thermometer (ET) system that will be used on the LDEF-1B mission.

The ET system concept is functionally illustrated in figure 1. Two plastic sheets are mounted above the detector stacks as shown. The upper sheet is movable and its position relative to the lower sheet is controlled, as a function of the temperature of the detector stacks, by the TAD. During the postflight analysis of the etched plastics, the temperature of the stack at the time a given track is produced will be determined by aligning the track etch pit in the movable sheet with the track etch pit in the fixed sheet and noting the stack temperature that was required for the driver to so position the sheets. The pits were obviously so positioned when the track was originally produced.

The specific requirements which were imposed on the TAD design to ensure that its performance will satisfy the ET requirements for the LDEF-1B cosmic ray experiment are as follows:

(1) Temperature range: -62°C(-80°F) to +49°C(+120°F)
(2) Displacement over temperature range: 5.08 cm (2.0 in.)
(3) All materials must be non-magnetic
(4) Fluids must be non-hazardous for Shuttle operations
(5) Accuracy of .046 cm per degree C(.010 in. per degree F)
(6) Adequate axial stiffness to restrain attached ET sheet during launch and landing vibration environment
(7) Minimum size and weight
(8) Maximum dimensions: 3.332 cm (1.312 in.) wide, 3.510 cm (1.382 in.) deep, and 109.38 cm (43.06 in.) long
(9) Reliability

OPERATION

The operation of the TAD, as schematically shown in figure 2, is a result of the expansion or contraction of an incompressible fluid as the temperature of the fluid changes. A coil spring controls the position of the output shaft by applying a resisting force to the pressure force on the piston. The system will remain in equilibrium as long as the spring force balances the piston pressure force.

The operation of the TAD is dependent on the thermal expansion of the charging fluid. Referring to figure 3, potential energy is stored in the bellows and coil spring when the TAD is pressurized at room temperature. As the temperature decreases and the volume of fluid contracts, the bellows and coil spring release some of their potential energy to keep the bellows piston area in contact with the oil column. As the temperature increases, potential energy is increased in the bellows and coil spring. Since the output shaft is welded to the bellows plug, the output shaft tracks the movement of the bellows and fluid.

HARDWARE

The sizing of the driver is dependent upon the coefficient of thermal expansion of the charging fluid; therefore, the first component of the driver selected is the fluid. Dow Corning 200, 10 centistokes silicone oil was chosen for the following reasons: (1) large rate of thermal expansion, (2) high flash point, (3) low pour point, (4) non toxic, (5) readily available, and (6) relatively inexpensive. The outside diameter of the TAD was constrained to be no greater than 3.332 cm (1.312 in.) in order to fit in the allotted experiment canister space. Seamless, 321 stainless steel tubing, 3.175 cm outside diameter x 2.565 cm inside diameter (1.25 in. x 1.01 in.) was selected for the pressure shell. A thin, flexible metal bellows was selected as a means of storing and releasing potential energy during temperature cycles while sealing around the output shaft to prevent fluid leakage. The bellows was designed to function over the operating displacement range for $>10^6$ cycles while mechanical stresses remain within the proportional limit of the bellows material. A coil spring was designed to increase the axial stiffness of the TAD and to assist the bellows by releasing potential energy at the lower temperature range where the bellows has expanded to its "as-formed" length. The bellows material is 321 stainless steel, .0152 cm (.006 in.) thick. The coil spring material is Inconel X750, .318 cm (.125 in.) diameter wire. The output shaft is made of 321 stainless steel rod, .794 cm (.3125 in.) dia. The output shaft is guided in the front support by a bushing, and supported in the oil reservoir by a cylindrical guide. Both of these parts are made of phosphor bronze, CDA 54400. The phosphor bronze provides a good sliding surface on stainless steel while closely matching the thermal growth rate of stainless steel. The coil spring is captured between the cylindrical shaft guide and a spring retainer made of 347 stainless steel. The front support and rear support are made of 347 stainless steel.

ASSEMBLY AND PRESSURIZATION

After machined parts are completed and the bellows is formed, the bellows assembly is fabricated by loosely assembling the front support, bellows, bellows plug, and output shaft. Weld joints at three locations seal the bellows to the front support, bellows plug, and output shaft (figure 4). The bellows assembly is placed inside the pressure shell and a full penetration weld joins the front support and pressure shell. From the open end of the pressure shell the remaining internal parts are assembled in the following sequence: (1) coil spring retainer, (2) coil spring, (3) shaft guide, and (4) capture nut (figure 5). Figure 6 shows the assembly of the internal components; for clarity, the pressure shell is omitted. The capture nut is torqued in order to stretch the bellows .96 cm (.38 in.) which increases the effective length of the bellows. The rear support is positioned in the pressure shell and a full penetration weld joins the two (figure 7). Radiographic and dye penetrant inspections of each weld are performed sequentially during the assembly process to ensure the integrity of each joint. After the TAD components are assembled, a vacuum pump is attached to the fill tube through a valving arrangement. The internal cavity of the driver is evacuated and valved off. A valve attached to the liquid sump/pump is opened, allowing the silicone oil to fill the driver. The hand pump is then operated slowly to increase internal pressure to ~1723.8kPa (~250 psig). Since manufacturing variations in the bellows and coil springs will result in slightly different spring rates for each item, shaft displacement rather than internal pressure determines when the pressurization process is completed; thus ensuring a practically equal amount of fluid is pumped into each TAD. The fill tube is flattened, pinched off (under pressure), and dipped in solder. The TAD assembly and pressurization procedure is now complete.

TESTING

Three types of tests are conducted on the TAD: (1) pressure testing to verify structure integrity, (2) thermal testing for calibration and survivability demonstration, and (3) vibration testing to verify workmanship and structural integrity for Shuttle induced accelerations.

Pressure testing of the TAD is an integral part of the pressurization procedure. As the output shaft reaches its calculated extended position at ~1723.8kPa (~250 psig) internal pressure, it is restrained from further movement while internal pressure in increased to ~2585.6kPa (375 psig) which is approximately 1.5 times nominal pressure. The shaft restraint is necessary to prevent the bellows and coil spring from collapsing excessively, which would exceed the material yield strength of one or both.

Thermal testing of the TAD is conducted in a NASA/LaRC thermal vacuum chamber. The driver is suspended in a bath of Dow Corning 200 silicone oil and a Direct Current Displacement Transducer (DCDT) is attached to the output shaft. Thermocouples are attached to the outer surface of the pressure shell, suspended in the oil bath, and suspended in the vacuum chamber. The chamber is cooled by liquid nitrogen which becomes gaseous as it is injected into and circulated around the chamber. The chamber is warmed by resistance heaters. Since the thermal chamber can be controlled to only $\pm$2.8°C($\pm$5°F), the oil bath is used to dampen the temperature variations.

Vibration testing of the TAD to achieve desired acceleration levels is conducted on an Unholtz-Dickie shaker fixture at NASA/LaRC. The driver is mounted in a cavity of the experiment canister and accelerated to 5.0g's in the longitudinal axis, 16.5g's in the axis orthogonal to the longitudinal axis, and 10.0g's in the other orthogonal axis. These acceleration levels generate loads which are 1.4 times limit loads due to Shuttle launch or landing.

CONCLUSIONS

The TAD is a precision, large force driver that meets the very stringent requirements of the ET system for the LDEF-1B cosmic ray experiment. Forty-five TAD's will be flown on the LDEF-1B mission, and it is expected that TAD's will also find use in a number of other space and terrestrial applications. With properly selected fluids, fluid volumes, and bellows sizes, TAD's can offer a wide choice in performance variables--namely displacements, operating temperatures, driving forces, and response times.

TAD's obviously have applications in fluid control systems where precision valve controls are needed; for example, in manufacturing processes and in safety control systems.

A single TAD may be used to drive a large bank of thermal control louvers for spacecraft or for terrestrial buildings. The fact that part of the fluid volume can be remotely located and piped to the driver allows flexibility in the thermal control designs and, in some cases, performance improvements.

TAD's may also be used to compensate for thermal expansion and distortion of spacecraft structures where extreme dimensional stability is essential.

In conclusion, the TAD features may be summarized as follows:

- Precision, thermally-activated displacement and position control
- Wide choice in performance and operating variables
- Reliablility, and
- No power required

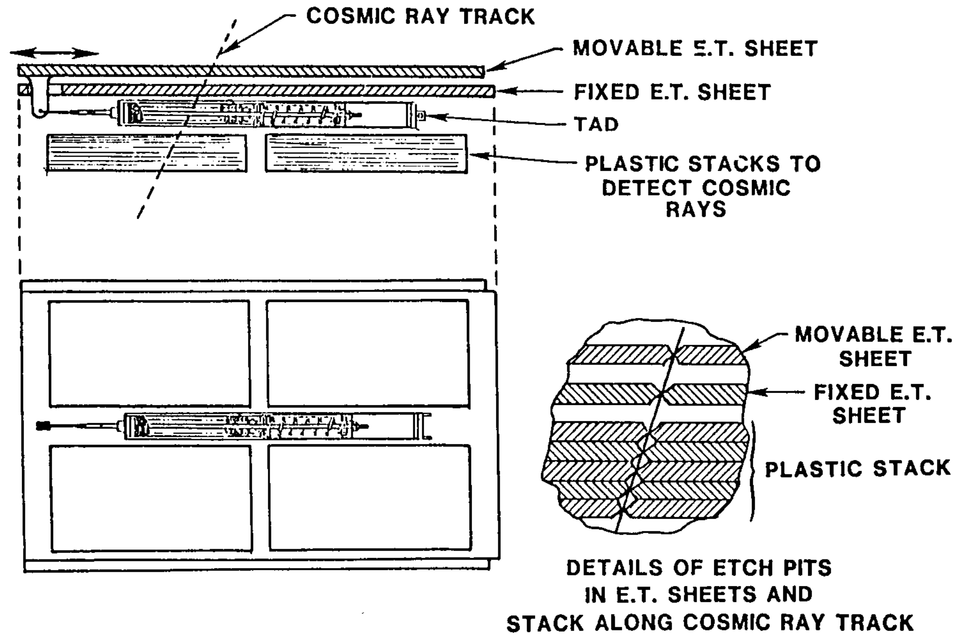

Figure 1. - Schematic of event thermometer for cosmic ray experiment to fly on LDEF 1B mission.

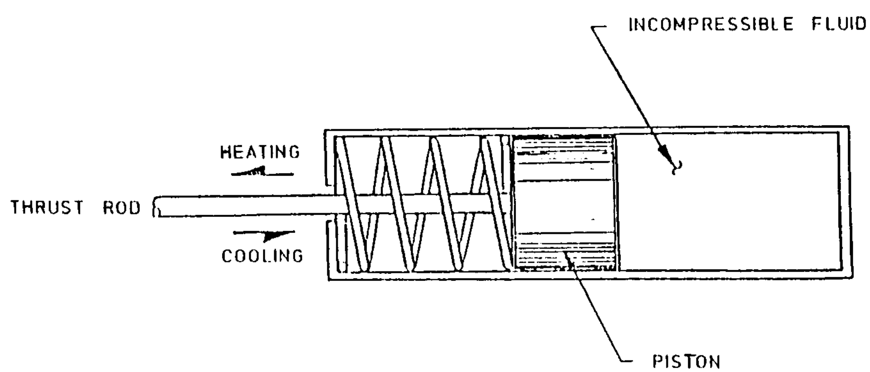

Figure 2. - Operating principle schematic.

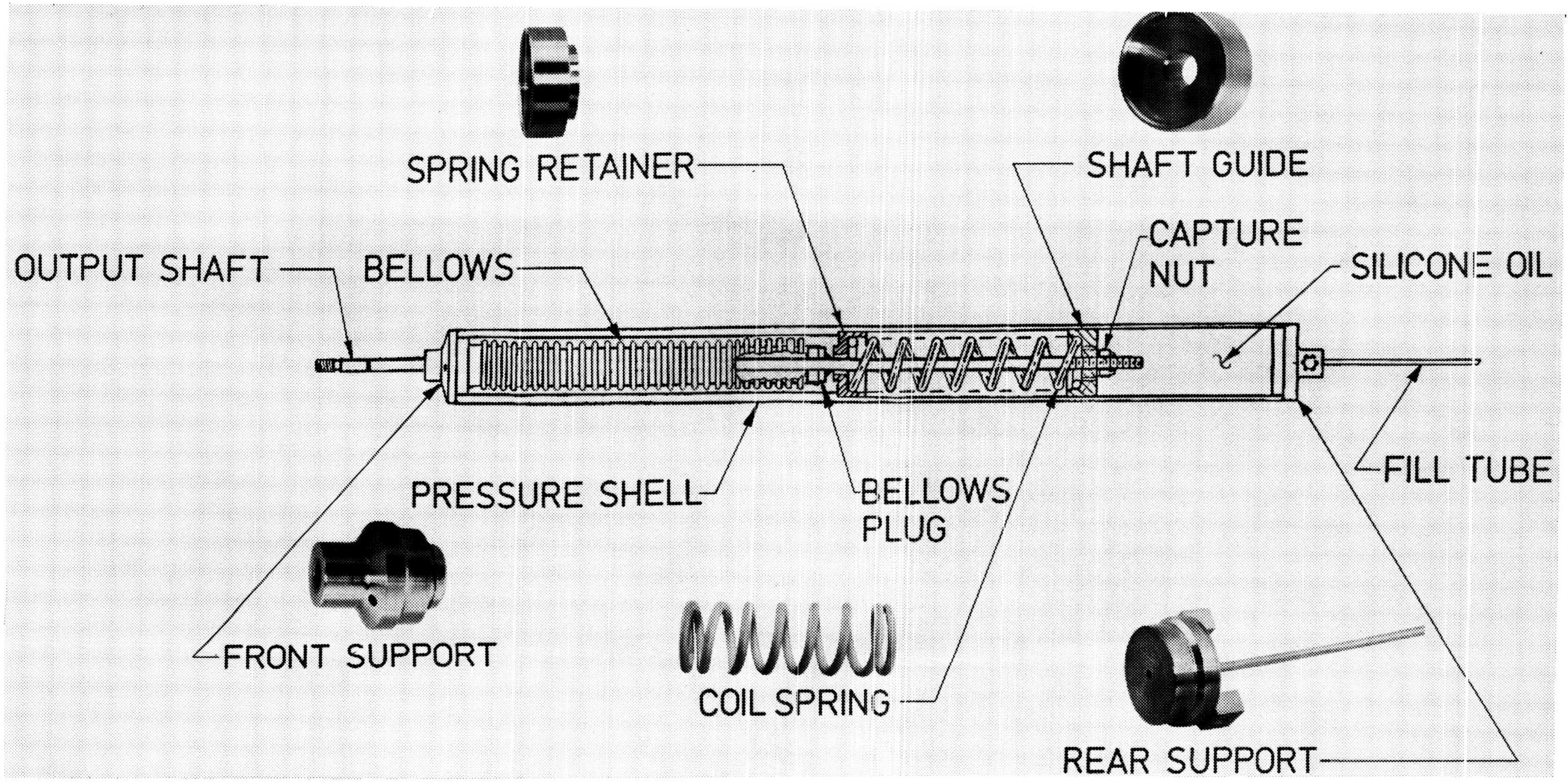

Figure 3. - Thermally-activated driver schematic.

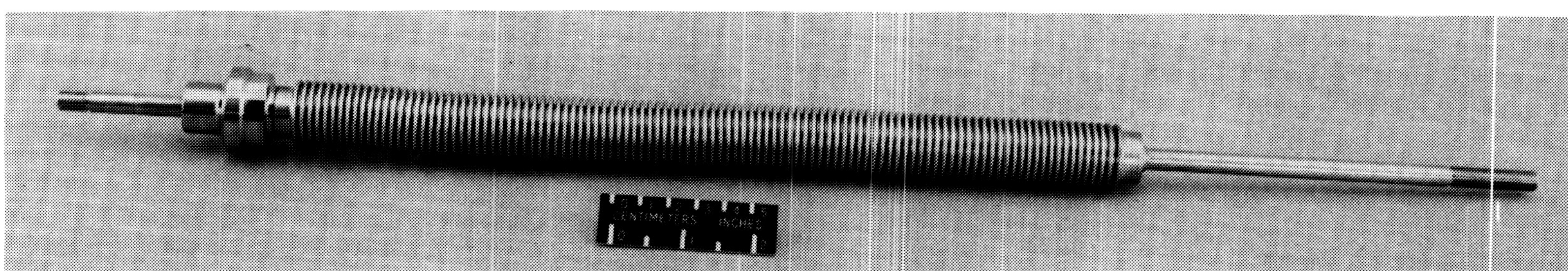

Figure 4. - Bellows assembly.

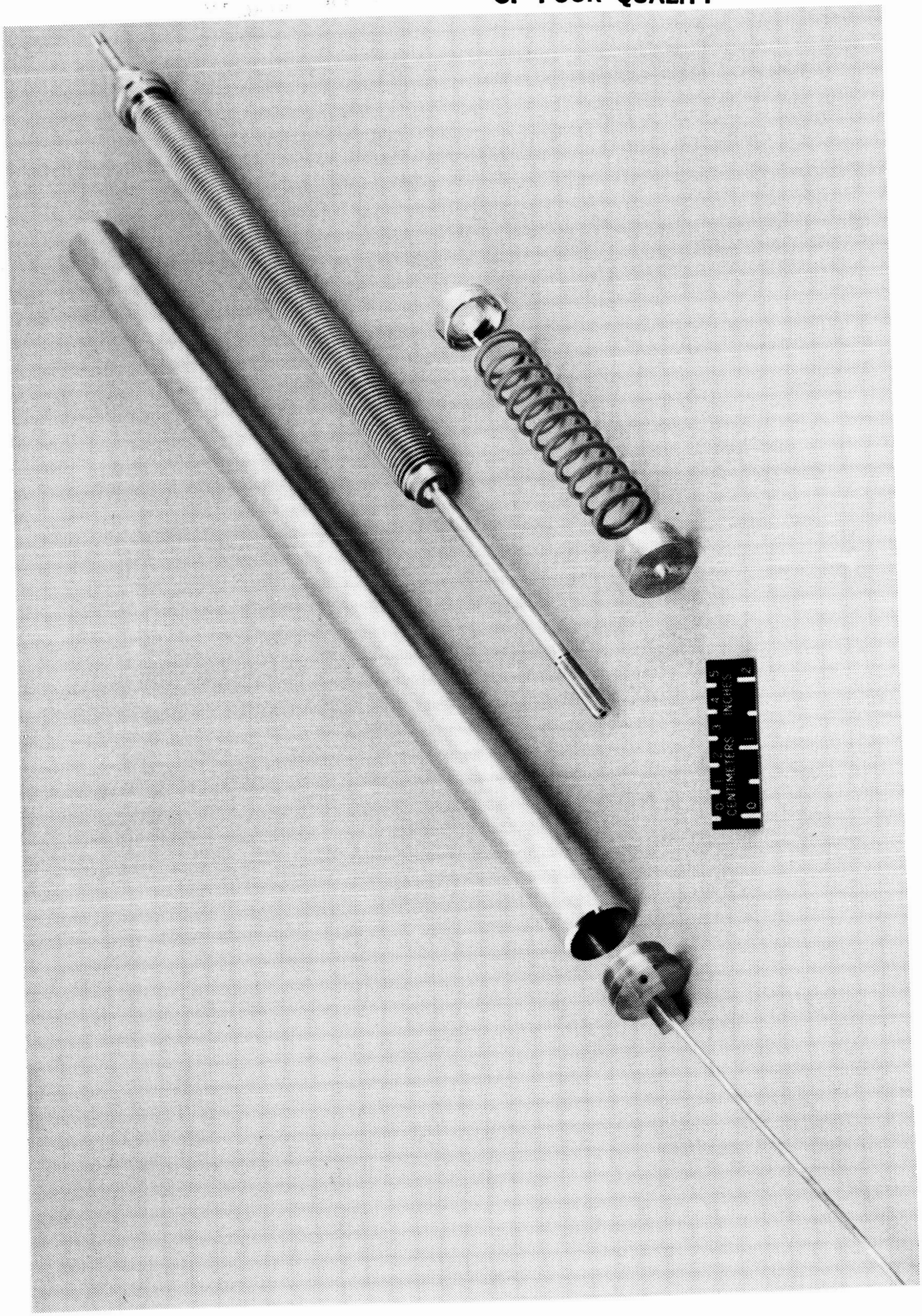

Figure 5. - Thermally-activated driver components.

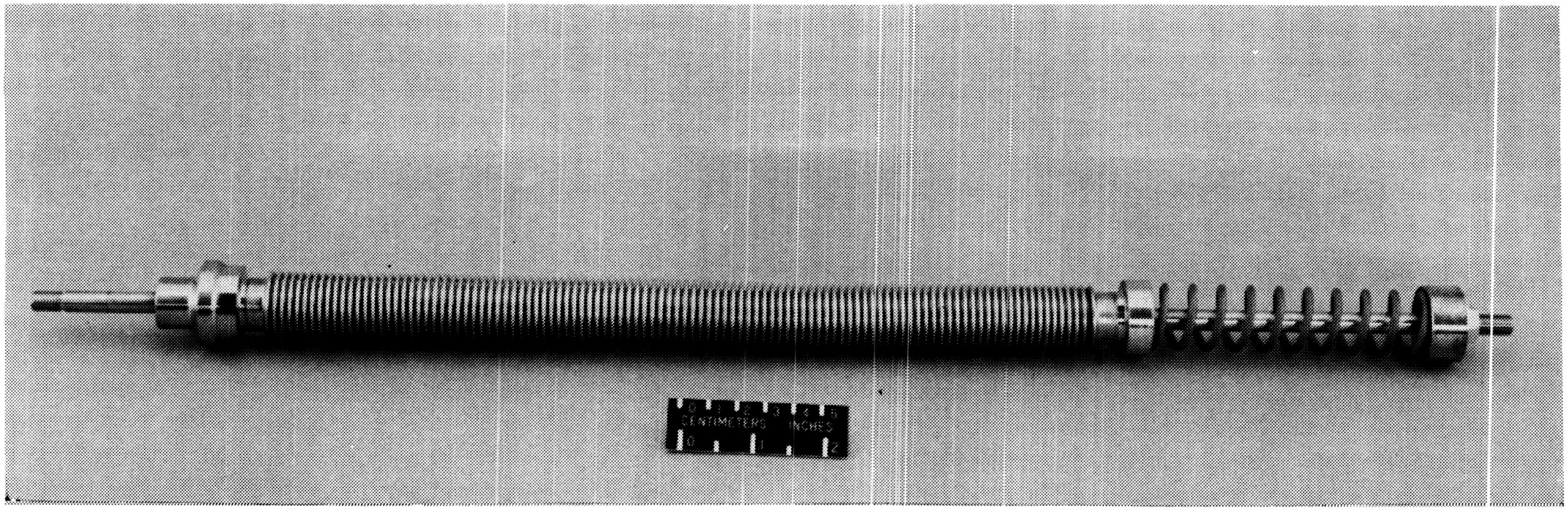

Figure 6. - Thermally-activated driver assembly without pressure shell.

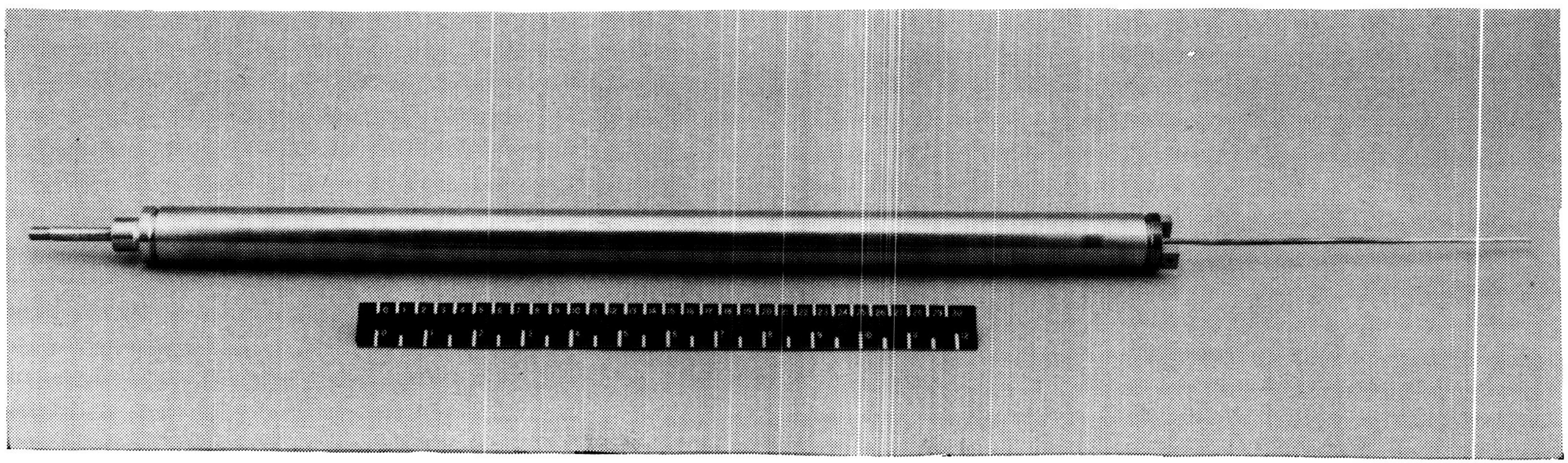

Figure 7. - Thermally-activated driver final assembly.